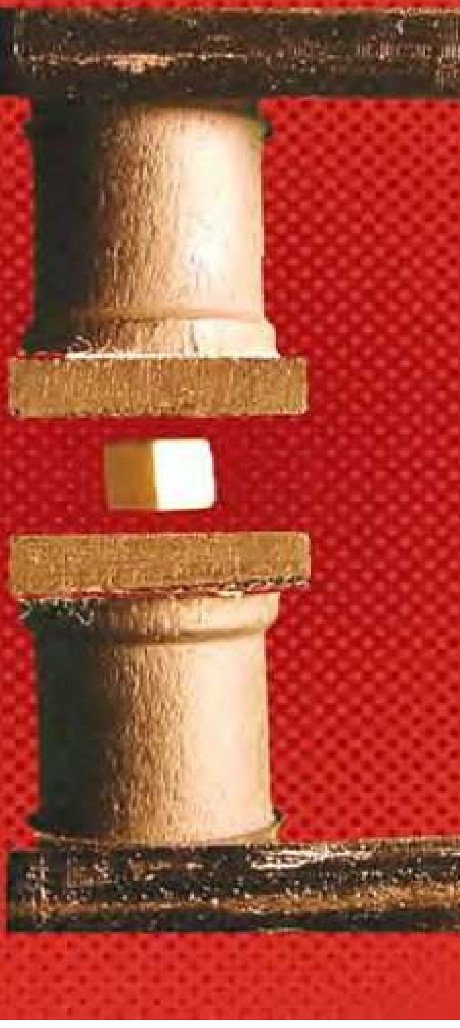
MONDO MAGNETS

40 ATTRACTIVE (AND REPULSIVE) DEVICES & DEMONSTRATIONS

Build and Explore Super Levitrons, Floating Globes, Magnetic Arches, Linear Accelerators, and More



FRED JEFFERS

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CHICAGO REVIEW PRESS

Library of Congress Cataloging-in-Publication Data

Jeffers, Fred.

Mondo magnets : 40 attractive (and repulsive) devices and demonstrations / Fred Jeffers.

p. cm.

ISBN-13: 978-1-55652-630-5

ISBN-10: 1-55652-630-X

1. Magnetism—Experiments—Popular works. 2. Magnetics—Experiments—Popular works. I. Title.

QC753.5.J44 2007

538.078—dc22

20060264

Cover design: Monica Baziuk

Interior design: Rattray Design

Interior illustrations: Michael Rattray

All photos courtesy of the author except page 6, which is courtesy of Fred Chamberlain.

Published by Chicago Review Press, Incorporated

814 North Franklin Street

Chicago, Illinois 60610

ISBN-10: 1-55652-630-X

ISBN-13: 978-1-55652-630-5

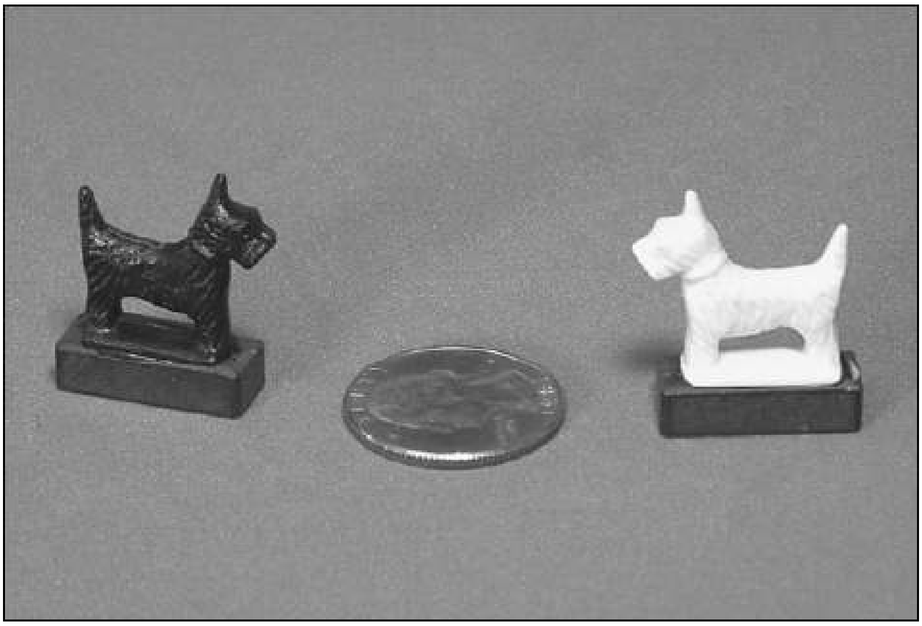
Printed in the United States of America

5 4 3 2 1

Contents

Introduction

Welcome to the wondrous world of magnetism! When I was a small child I was given a pair of to —small magnetic Scottie dogs—to play with. I have been fascinated by magnetism ever since. was recently delighted to find that, after more than 60 years, the magnetic toy dogs are still so today (they can be found at www.lehmans.com).



Magnetic Scottie dogs

During my 38-year career in industrial magnetic product research I have developed, discovered, ar elaborated on many remarkable magnetic physics demonstrations, or "magic tricks." Each is based o real magnetic physics, and they all produce surprising and seemingly impossible effects.

I presented some of these demonstrations in a series of Magnetic Magic Show lectures after I w named an IEEE (Institute for Electrical and Electronic Engineering) Distinguished Lecturer in 1999. Tl lectures were so successful, with a total of more than 3,000 people attending my shows, that I w motivated to write down the demonstrations in the form of this book.

These experiments illustrate and bring to life important concepts in the very poorly understood fiel of magnetism. Many of the effects demonstrated at first baffle even magnetic experts, to the extent th they appear to be magic. However, to paraphrase Arthur C. Clarke, magic is just a word that mear "technology we don't understand yet." This book shows how each of these 40 mesmerizing "tricks' works; once the secrets are revealed, the explanations of the "magic" involved are relatively simple understand. Enjoy!

Magnetic Money, Rocks, Beach Sand, Total® Cereal, and Dirt

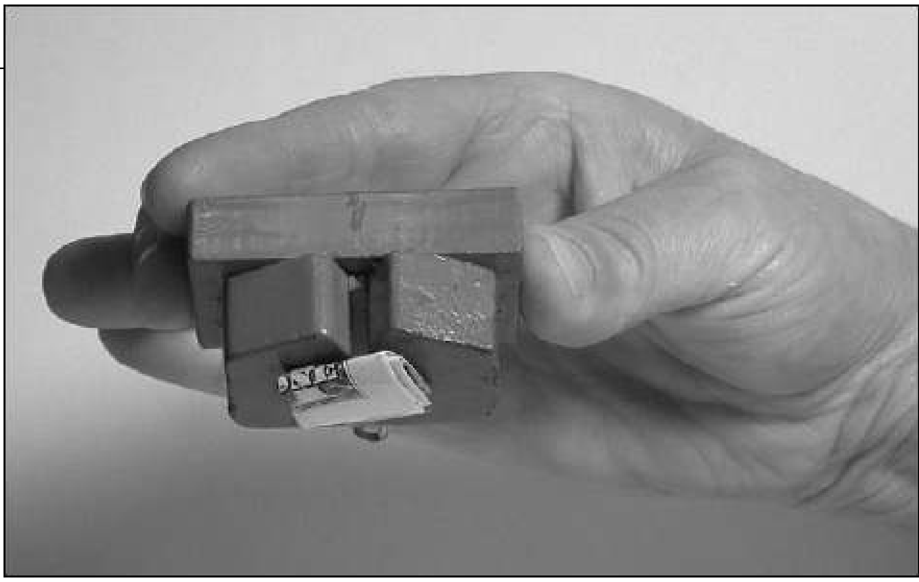
It's shown that money, many rocks, beach sand, Total® cereal, and even common dirt are magnetic.

Materials

U.S. $1 bill
Cellophane tape
Very strong magnet (such as an NdFeB magnet)
Rock (see page 2)
Several handfuls dry beach sand
Two small, nonmagnetic jars (such as glass baby food jars) and their lids
Several handfuls Total® cereal
Medium-sized bowl
Pestle or heavy spoon
Several handfuls dirt

Elements of magnetic money, rocks, beach sand, Total® cereal, and dirt

Fold the $1 bill tightly into a roughly ½-inch square and hold it together with cellophane tape, shown. Show that the $1 bill is attracted to the strong magnet.

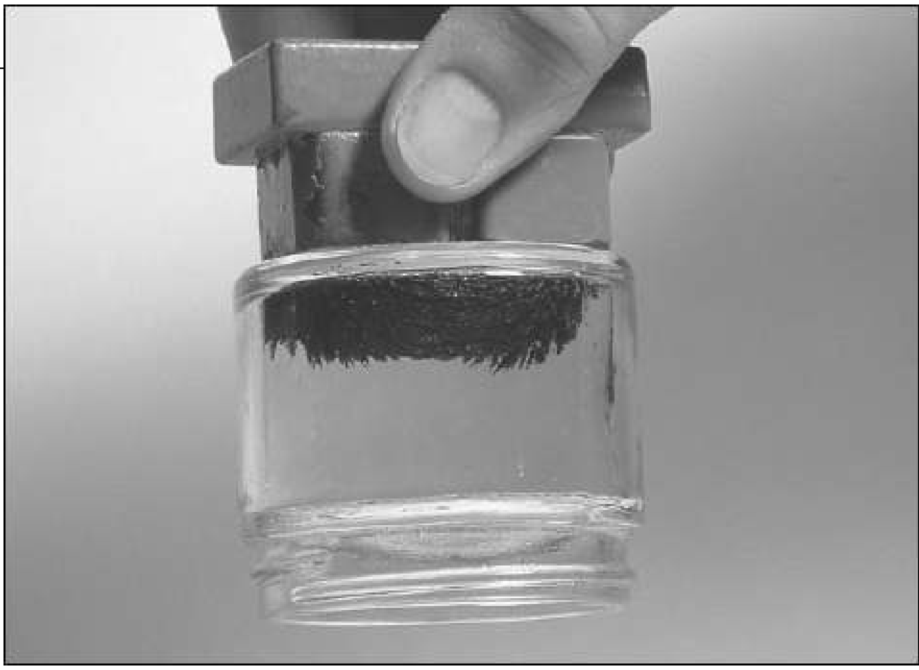


Magnetic money

Next, show that the rock can be suspended under the magnet. You will need to find a suitable roc before you begin—not all rocks are attracted to a strong magnet. Go to a beach or a streambed anywhere where there is a large variety of rocks, touch your strong magnet to different small stones, ar in a short time you should be able to find one that will work for this demonstration.

Magnetic rock

Place a large handful of beach sand in one of the jars and secure the lid. Turn the jar upside dow and tape the magnet to its bottom. Shake the jar briskly for a few minutes, then remove the lid ar slowly pour out the sand. A tablespoon or so of coarse, strongly magnetic black powder will remain the jar, attracted to the magnet.

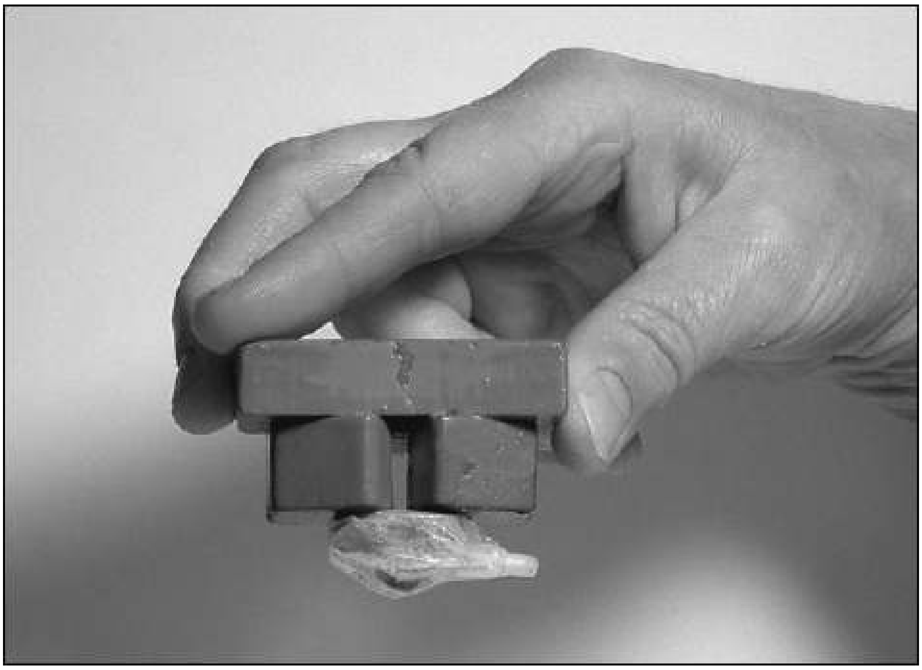


Magnetic beach sand

Remove the magnet from the jar and pour the black powder into another small jar for safekeepin Using the same sand, repeat the procedure a few times to separate a bit more magnetic material from th sand. Transfer the black magnetic powder to the other small jar and set aside.

Using additional handfuls of sand, repeat the process, transferring the black magnetic powder tha collected to the second jar as you go. (This powder can be used to make a crude but effective Magnet Mountain demonstration, which is described in Experiment 7.)

Place a large handful of cereal in the bowl and, using the pestle or spoon, grind it into a very fi powder. Pour the powdered cereal into one of the jars and secure the lid. Turn the jar upside down, tap the magnet to the bottom of the jar, and briskly shake the jar for a few minutes. Remove the lid ar slowly pour out the powdered cereal. About a teaspoon of magnetic material will remain inside, attracte to the magnet. You may have to repeat this process a few times, using new bowls of cereal, to collect significant amount of magnetic material. Shown on page 4 is a small amount of magnetic cereal matt suspended in a plastic bag.



Magnetic Total® cereal

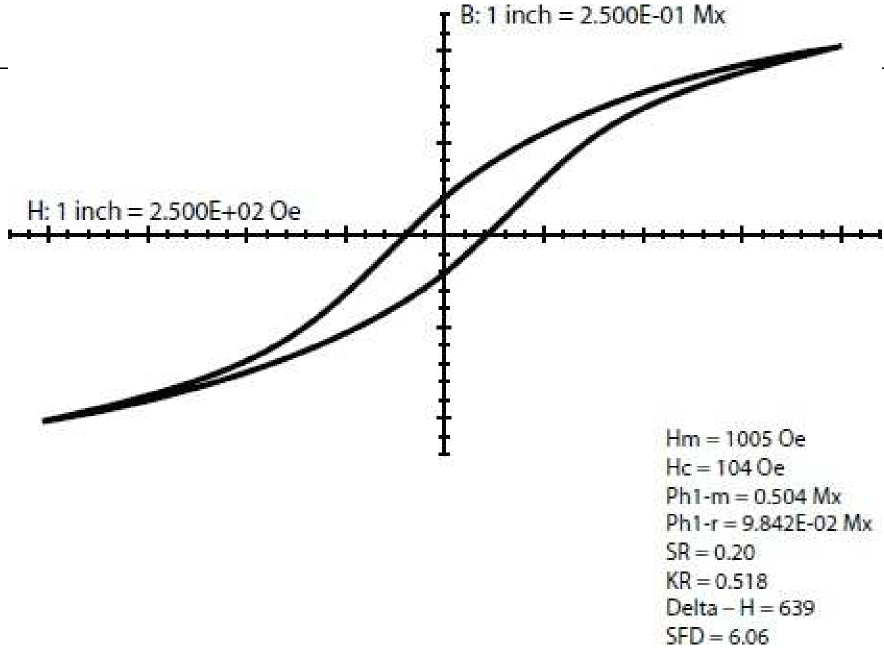
Finally, take a few handfuls of ordinary dirt from the garden and refine it in the same manner as f sand. This photo shows the jar of magnetic dirt suspended below the magnet.

Magnetic dirt

The Science Behind It

Why are all these things magnetic?

In each case, the black magnetic material that's collected is iron oxide. Iron is the fourth most abundar element in the earth's crust. The most abundant iron oxide is black Fe_3O_4, which is strongly magnetic. $1 bill is magnetic because the black ink on the portrait side of the bill is loaded with black iron oxi Fe_3O_4 pigment. The bill contains only about 5 mg of the oxide. The bill weighs almost exactly 1 gm, s the Fe_3O_4 present in the pigment is easily holding up more than 200 times its own weight! This Fe3C pigment was originally put in the ink to make it black, not to make it magnetic. The *hysteresis loop* of $1 bill is shown below. The *coercivity* is about 100 Oe and the *remanent moment* is appreciable.



Hysteresis loop of a $1 bill

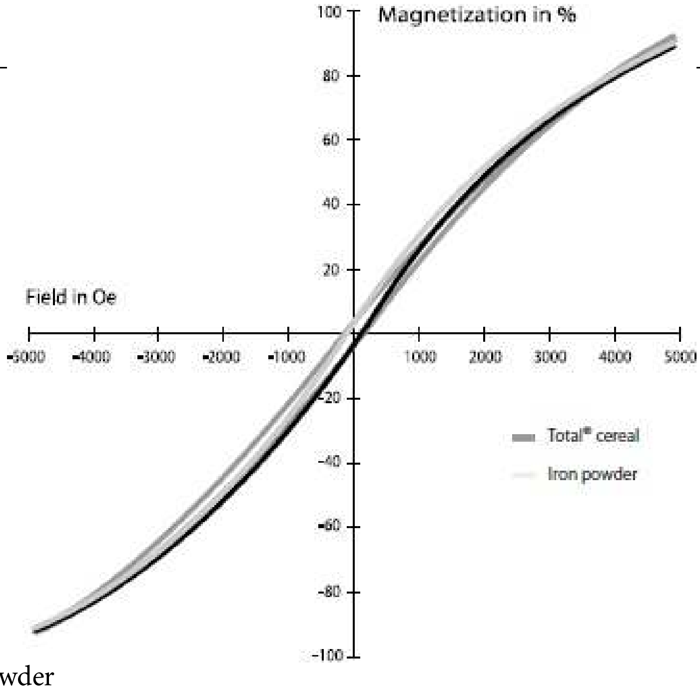
The image on the next page was made by scanning the surface of a $1 bill with a magnetic read hea similar to those used in modern tape recorders and hard disk drives. (The image is courtesy of Fre Chamberlain, who was at San Diego Magnetics at the time that he provided it.)

Magnetic image of a $1 bill

Comparing the magnetic image above to an actual dollar bill, the observant viewer will note that t treasury seal on the left side of the portrait is black, but is not magnetic. That is because the black ink the seal contains no Fe_3O_4. This fact is the basis of some simple counterfeit currency detectors.

The rock shown in this experiment is magnetic because it also contains Fe_3O_4. About 1 in 2 Southern California beach rocks is slightly magnetic, while about 1 in 100 rocks is magnetic enough be picked up.

Below is an M-H loop of the powdered cereal. Also shown is an almost identical loop of metallic ir powder.



M-H loops of Total® cereal and iron powder

The obvious conclusion from this plot is that Total® fortified cereal is “fortified” with iron that ha been added in the form of metallic iron powder. It remains to be seen if metallic iron is digested an absorbed by the body.

The beach sand and dirt both contain varying amounts of Fe_3O_4. The rock, sand, and dirt all hav M-H loops very similar to that of the $1 bill, because all three contain small particles of Fe_3O_4.

The Super Strong Magnetic Nail

A common nail is used to pull a string of small steel objects off a very strong magnet. The objects rema suspended under the nail until the magnet is removed, whereupon they fall off.

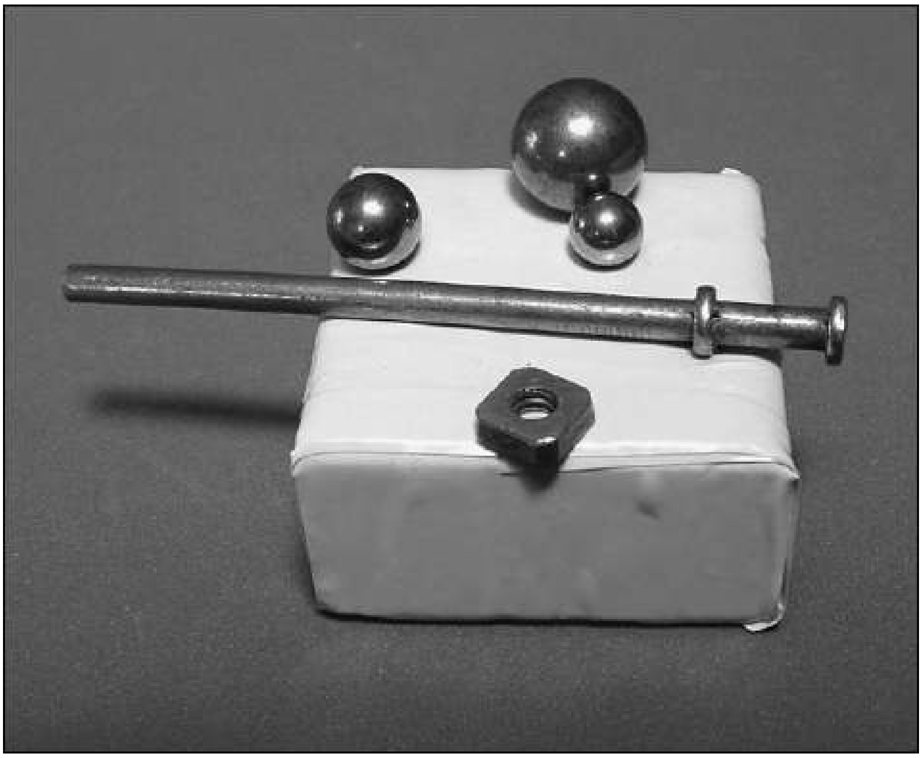
Materials

8-cm long iron framing nail

3 common steel balls measuring 1.3 cm, 1 cm, and 0.8 cm, respectively

1-cm square steel nut

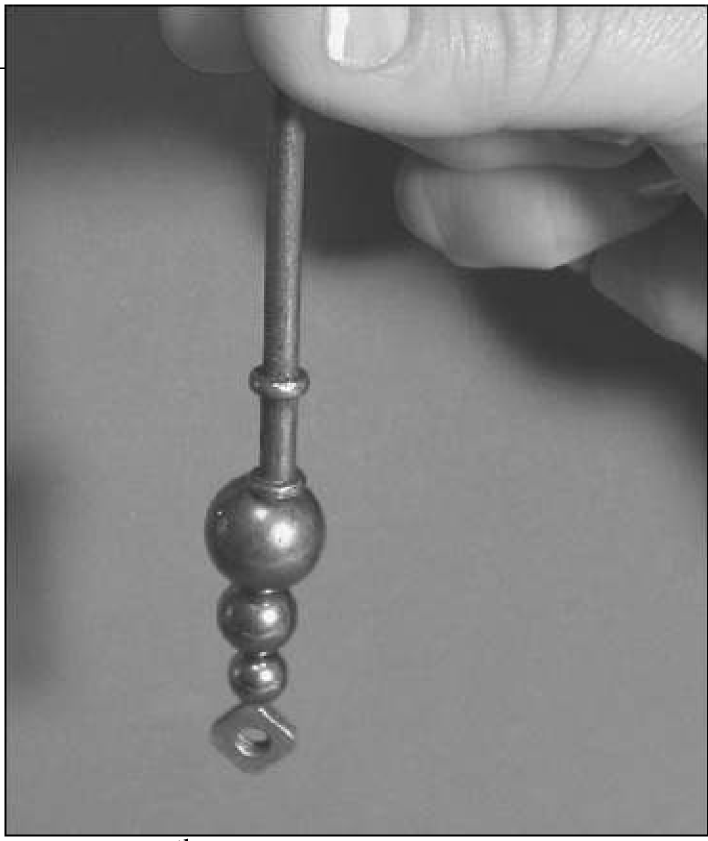
Very strong 5-cm by 5-cm by 2.3-cm NdFeB magnet (magnetized in the 2.3-cm direction)



Super strong nail equipment

A nail alone is not a magnet and won't pick up anything. Most people are very surprised to see, the that a nail will pull small objects off a strong magnet, one at a time, in a long string.

Place the steel balls and the nut on the magnet. Pick up the nail and hold it so that its head pointed toward the magnet. Place the nail head on the large ball and lift the ball, being careful to pull up and away from the *center* of the magnet. Next, touch the large ball to the medium-sized ball and l it from the center of the magnet. Continue with the small ball and then the nut, as shown belo Carefully raise the string of objects above the magnet. When the objects are a distance of 50 cm (2 inches) or so above the magnet, remove the magnet; the string will remain suspended from the nail hea



String of objects suspended below the super strong nail

Then, slowly place the magnet back under the suspended string and say a few magic magnetic word such as “gauss” or “oersted.” Slowly lower the string of objects toward the center of the magnet. At distance of about 15 cm (6 inches), everything will abruptly fall off the nail and back onto the magnet.

Here’s the trick: while everyone is watching the string of objects hang in the air and wondering wh they don’t fall off the nail head, discreetly turn the magnet over. As the nail and the objects come clos to it, the inverted magnet demagnetizes the nail; the force disappears, and the small objects fall off th nail head.

The Science Behind It

The field generated by the magnet magnetizes the nail by a process called *magnetic induction*. The na used in this experiment is very easily magnetized parallel to its length because it’s made of almost pu iron. It has a much higher maximum magnetization, or *saturation magnetization*, than the magn below it. In other words, the nail can become even more strongly magnetized than the magnet itself.

When the nail and string of objects are removed from the magnet, they retain some *remane magnetization* even in the absence of the magnet’s field because they have a low, but nonzero, coercivit Therefore, they remain stuck together because they are still partially magnetized.

The magnetic field at the head of the magnetized nail is very intense, but its intensity decreas rapidly as distance between the magnet and the nail increases. Hence, the force exerted by the nail greater than the force exerted in the center of the magnet, and all of the objects can be lifted from th magnet’s center quite readily. However, if you tried to pull objects from the edges of the magnet, yo would not be able to. The field there is large and it changes rapidly with distance, so the force is muc stronger at the edges of the magnet than it is in the center of the magnet.

A Variation

A very subtle extension of this trick is the demonstration that, unlike the behavior of the string of objec when *only* the large ball is lifted off the magnet and raised up, at some point it always falls off the nail.

In the earlier experiment, the combination of the nail and objects results in a “string” that is so lon that the *demagnetizing field* at the end of the nail is quite small. This results in a relatively larg magnetization in the end of the nail that produces a force strong enough to support the entire strin When only the large ball is picked up, the demagnetizing field at the end of the nail is larger, and as result the magnetization in the end of the nail is smaller. The resultant force is not strong enough t support the single ball in the absence of the magnet, and it falls off when the magnet is removed.

Experiment 3

The Magic Table Knives

It's shown that common stainless steel table k nives will stick together when they are magnetized. Tw knives can even be lifted off the table by a third, proving that the force of attraction is very stron However, there is almost no force of repulsion when one knife is reversed.

Materials

Strong magnet

Three ordinary stainless steel table knives with solid handles

Use a strong magnet to magnetize each knife (labeled A, B, and C here for purposes of explanatio in the same direction, parallel to the length of each knife: place the tip of each knife in contact with t "north pole" face of the magnet and slide the knife down the magnet to the end of the knife's handl The primary field in the center of the magnet is perpendicular to the knife, but the transverse field at t trailing edge of the magnet is also large, so the last field seen as the knife moves over the magnet parallel to its length and is directed from the knife's hilt to its tip. In the last magnetizing step, place th handle end of the knife in the center of the north face of the magnet and lift the knife straight up. The place the tip of the knife in the center of the south face and again lift the knife straight up. The idea is t magnetize each knife in the same direction, parallel to its length.

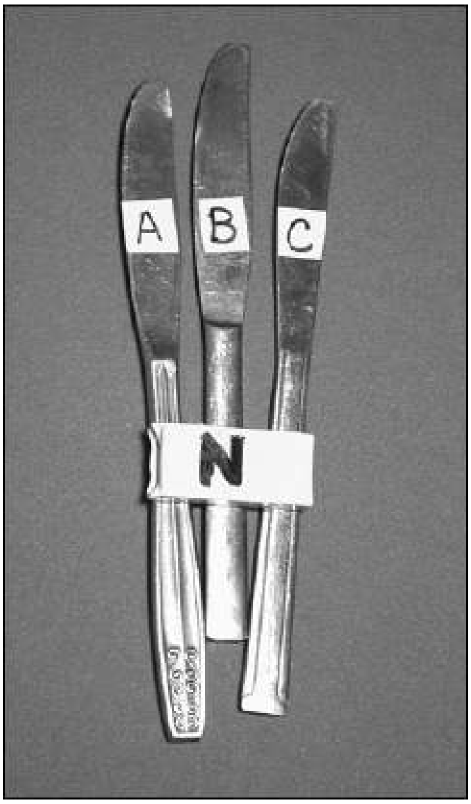
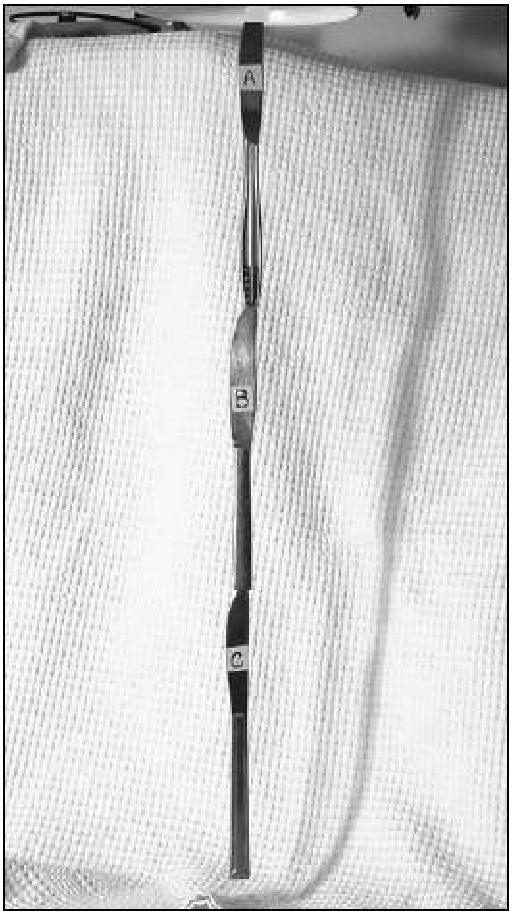


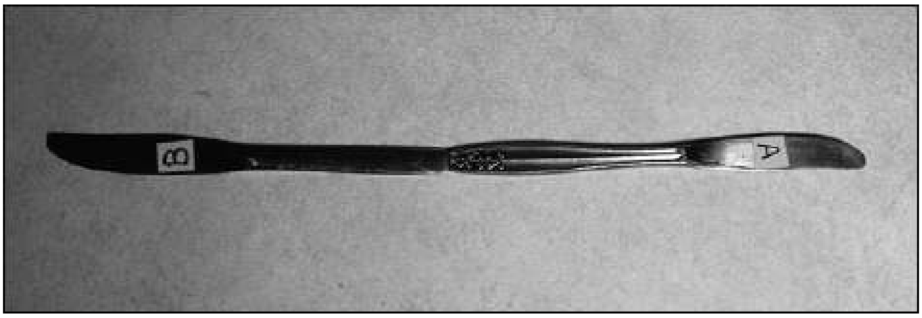
Table knives and magnet

The coercivity of a common stainless steel table knife is usually higher than 100 Oe, and the kniv retain a good deal of magnetization, like a permanent magnet when the magnetizing field is remove The mutual force of attraction is so strong that it's possible to pick up two knives, hilt to tip, with th third, as is shown here.

However, if you rotate one knife 180 degrees, you'll see that its force of repulsion is not even close t being strong enough to push another knife away. (This effect was discovered by Dr. Tom Howell.)



Two knives supported by a third



Apparently no force of repulsion

The Science Behind It

How can the force of attraction be so strong and the force of repulsion be so weak?

The explanation is that the fields near the tips of the knives are comparable to the coercivity. In th attraction mode, the field of Knife A enhances the magnetization of the tip of Knife B, and vice versa. A a result, the respective magnetizations at the tips are large, and the mutual force of attraction is strong.

In the repulsion mode, the field of one knife tends to *demagnetize* the tip of another. Hence, th magnetizations and the forces of repulsion are weak. However, the force of repulsion is not zero; this ca be easily shown by balancing one knife on the edge of a table. (The balanced knife may tend to rotate t the north in response to the earth's field.) Bringing another knife, in repulsion mode, within a centimete or so of the first knife easily causes the balanced knife to rotate away. This occurs because the field present at that distance of separation are so small that they do not demagnetize the tips.

A Variation

A final mystifying bit of table knife physics follows. In repulsion mode, if a finger is used to prevent th balanced knife from rotating, and the tip of the knife is carefully touched by the tip of another knife, very weak force of attraction may be observed. But this effect doesn't happen with all pairs of knives. I this experiment, Knives A and C and Knives B and C exhibit the effect, but Knives A and B do not!

What is happening? In each case where two knives show a weak force of attraction, one of the kniv has a higher coercivity than the other. Its field is thus large enough to locally reverse the magnetization the other knife at the point of contact. This produces the very weak attractive force. Because the fiel involved are so small, the effect is reversible, and it can be repeated at will without causing a change the magnetization of the knife.

The reason that pairs A and C and B and C exhibit the effect is that Knife C has a higher coercivit than either Knife A or B. The reason why the A-B pair doesn't show the effect is that Knife A has abou the same coercivity as Knife B. The tip of each knife is demagnetized to nearly zero when one is broug near the other, and no force of attraction occurs.

The Mysterious Magnetic Arch

Magnetic balls form an arch on a magnetic plate. The arch is shown to be stable even when the plate held vertically or upside down.

Materials

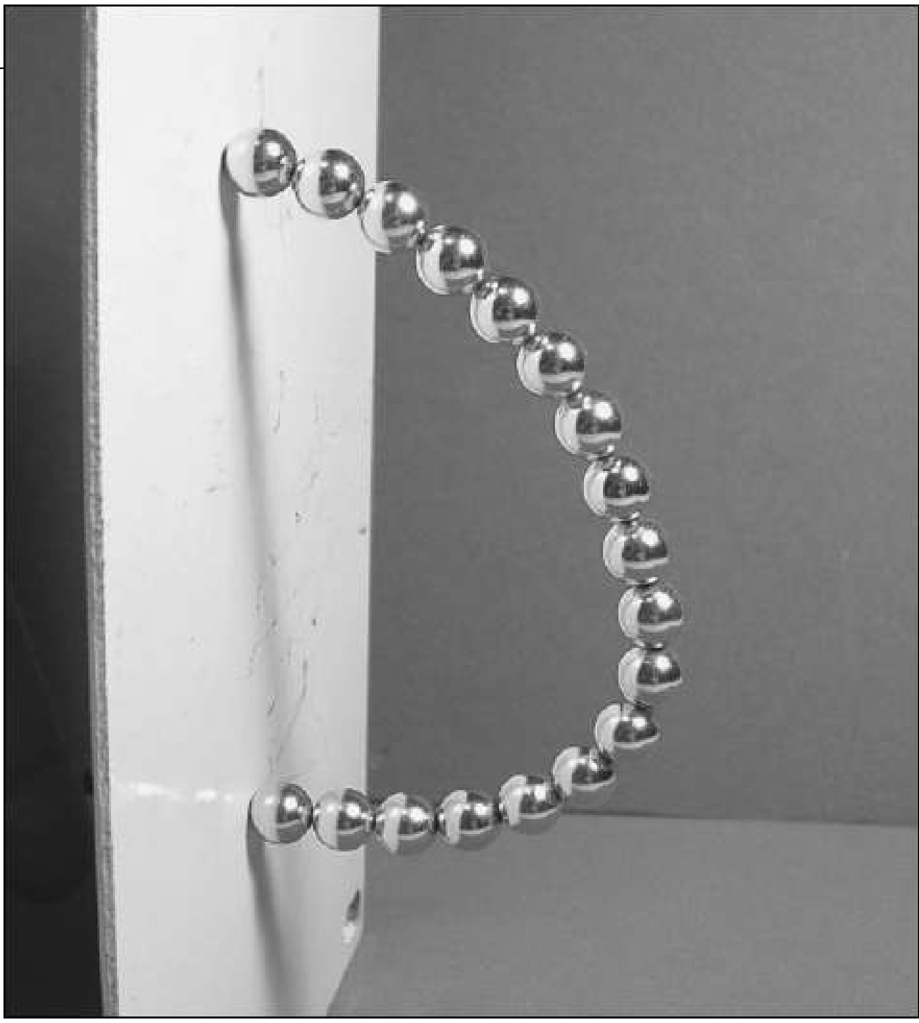
18 very strong 8-mm-diameter spherical NdFeB magnets (available from Engineered Concepts www.engconcepts.net) 5-inch by 7-inch, 40-mil-thick steel plate

Place the magnets on top of the steel plate as shown below. They will form a sturdy, symmetric arch

Magnetic arch components

Magnetic arch

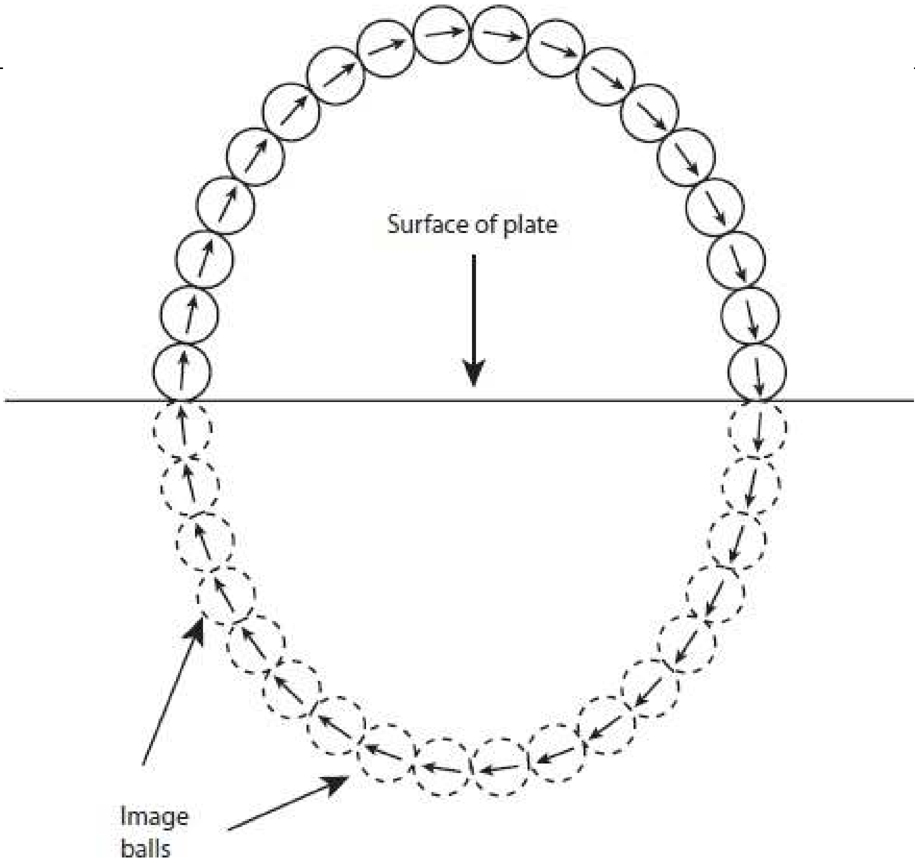
You will find that this arch is surprisingly stable and that it can be poked and prodded withou collapsing. The arch even remains stable when the plate is oriented vertically, though gravity will cause to sag slightly.



Magnetic arch held vertically

The Science Behind It

Each magnet in the arch is oriented in a very stable "head-to-tail" arrangement. When the balls a placed on the magnetic plate, a *magnetic image* is created inside the surface of the *high-permeabili* (easily magnetized) steel plate, similar to the reflection one sees in a mirror.



Magnetic image diagram

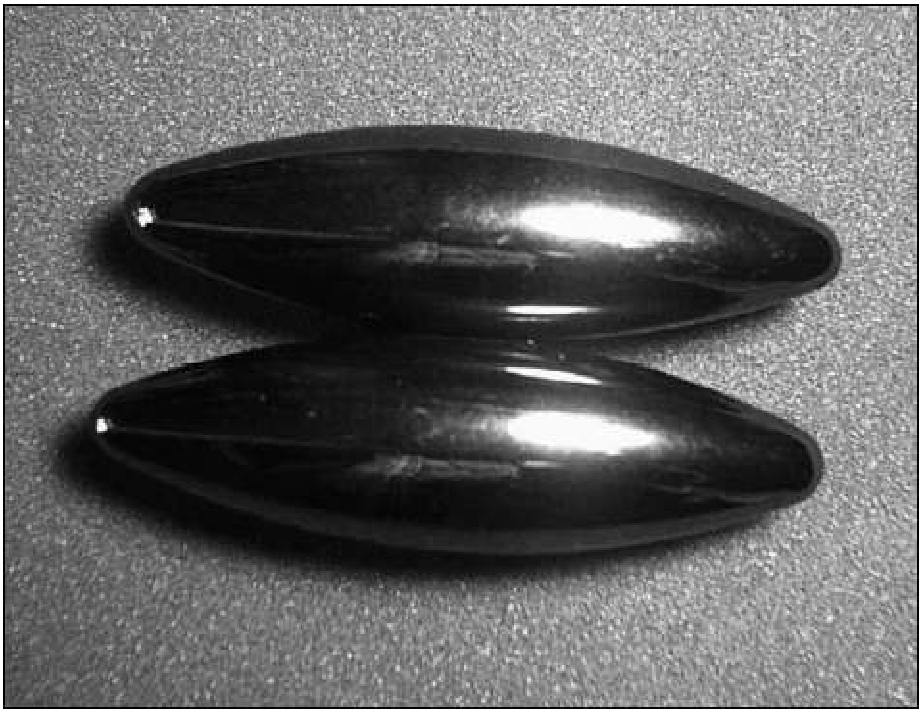
Away from the plate, the magnetic field generated by the magnetic image of the balls is identical t the field that would exist if the image balls were real, and the physical balls and the plate were n present. Because of the field emanating from the magnetic image balls, the actual balls on the plate ar the image balls are effectively arranged in a complete and stable circle, although only the arch (the “ha circle”) of the actual balls can be seen.

The Strange "Zinging" Magnets

Two oblong, football-shaped magnets are held in the hand, separated by a small distance. When they ar tossed in the air they snap together and emit a loud "zinging" noise.

Materials

Two oblong, ceramic barium ferrite magnets (available from Cyberguys, Inc., www.cyberguys.com/templates/searchdetail.asp?T1=250+0680 and many other Web site stores)



Zinging magnets

Hold the two magnets in the palm of your hand, using your thumb to keep them about an inc apart.

Zinging magnets ready to toss

Toss them into the air. As they snap together they will emit a loud “zinging” noise.

The Science Behind It

The magnets are made of ceramic barium ferrite and are magnetized through the small dimension. The are, of course, strongly attracted to one another. The ceramic material from which they are made is ver hard. If they are separated by an inch or so and thrown up into the air, they will snap together, boun apart and snap back together very rapidly, with only a small amount of energy loss per bounce. Becau the force of attraction is strong and the ceramic is very hard, the initial frequency of the magne bouncing apart and coming back together is a few hundred *hertz,* or Hz (cycles per second). Th frequency increases as the amplitude of the bouncing decreases. This causes the bouncing magnets emit a loud ZZZZZZZiiiiNNNNGGG noise.

For fun, try tossing the magnets to an unwary victim, saying, “Here, catch!” The zinging noise is ve disconcerting, and most people will fail to make the catch. (It’s best to pull this joke over a carpeted floo to avoid breaking the magnets.)